

UNCLASSIFIED

AD \_\_\_\_\_

THE EFFECT OF FATIGUE ON VISUAL SEARCH ACTIVITY

FINAL REPORT

JOHN A. STERN, PH.D.

1965-1972

Supported by

U. S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND

Washington, D.C. 20314

Contract No. DA 49 193 MD 2715

Washington University

St. Louis, Missouri 63104

This document has been approved for public release and sale; its distribution is unlimited.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

UNCLASSIFIED

Reproduced by  
NATIONAL TECHNICAL  
INFORMATION SERVICE  
U S Department of Commerce  
Springfield VA 22151

AD 750097

1972

121

UNCLASSIFIED  
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Behavior Research Lab, Washington University St. Louis, Missouri 63104		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP	
3. REPORT TITLE  THE EFFECT OF FATIGUE ON VISUAL SEARCH ACTIVITY			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report - 1965-1972			
5. AUTHOR(S) (First name, middle initial, last name) John A. Stern, Ph.D.			
6. REPORT DATE 1 July 1972		7a. TOTAL NO. OF PAGES 21 of text & tables	7b. NO. OF REFS 0
8a. CONTRACT OR GRANT NO. DA 49 193 MD 2715		8b. ORIGINATOR'S REPORT NUMBER(S) None.	
a. PROJECT NO.			
c.			
d.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.			
11. SUPPLEMENTARY NOTES  none		12. SPONSORING MILITARY ACTIVITY U.S. Army Medical Research & Development Command - Department of the Army	
13. ABSTRACT  This report reviews our work on a) the development of recording techniques for obtaining outputs from the manipulanda of helicopters (UH-1D) and automobiles, as well as techniques for processing such data. The majority of the report deals with the recording and utilization of measures of visual search activity for the assessment of pilot performance as a function of such variables as level of training, time on task, and sleep deprivation. During the contract period, we developed the necessary hardware for electrooculographic recording of visual search activity, and computer techniques for abstracting relevant information from these records. Two published studies utilizing these procedures are part of this report.  The report further details some further development of the application of our analytic programs to the evaluation of reading activity.			

DD FORM 1473  
1 NOV 65

REPLACES DD FORM 1473, 1 JAN 64, WHICH IS  
OBSOLETE FOR ARMY USE.

UNCLASSIFIED  
Security Classification

14.

KEY WORDS

LINK A

LINK B

LINK C

ROLE

WT

ROLE

WT

ROLE

WT

FINAL REPORT ON  
U.S. DEPARTMENT OF THE ARMY  
CONTRACT DA 49 193 MD 2715

by

John A. Stern, Ph.D.  
Professor of Psychology  
Washington University  
St. Louis, Missouri

1 July 1972

The work conducted during the seven year period of this contract is reflected in the annual reports and publications resulting from this research. This final report will attempt to summarize the research conducted and its possible utility to operational problems.

The initial focus of this research effort was the development of predictors of performance utilizing both behavioral and physiological measures. The task chosen for analysis was the piloting of a helicopter. Since for these early investigations no criterion measure of performance was available (though one was in the germinal stages of development by the Aeromedical Laboratory at Fort Rucker), we elected to make comparisons on our measures between a group of skilled pilots (criterion group) and groups of pilots developing the necessary skills to fly the UH-1D helicopter.

The behavioral measures selected for analysis were the outputs of the manipulanda utilized by the pilot in flying the craft, namely, stick (forward and backward, left and right), throttle, collective pitch, and tail rotor control. During the first contract year, we instrumented a H-34 helicopter assigned to the Aeromedical Laboratory collected preliminary data on 4 pilots, and put together a hybrid data reduction system consisting of a Pace analog computer and a PDP-5 digital computer at the Washington University Engineering Research Laboratories. A number of programs for processing and abstracting

this data were also developed. Problems encountered in this effort were numerous but were all successfully solved. A few of these problems will be identified here, principally to demonstrate that cooperation between service units at Fort Rucker were excellent, as well as demonstrating that the Air Force will cooperate with the Army.

1. Because of unavailability of an airborne tape recorder at Fort Rucker, one was borrowed from a nearby Air Force installation.

2. Because the electrical energy converter available in the helicopter was not adequate to handle the additional load imposed by the tape recorder, an additional converter was installed with the aid of the civilian aircraft maintenance unit on the base.

3. Since attachment of sensors to manipulanda posed a potential hazard for flight performance, all such installation had to be cleared with the relevant aircraft safety personnel. They again were most cooperative and helpful.

The experimental design developed for the first study was concerned a) with the consistency with which a pilot performed a series of specific maneuvers and b) to assess amount of inter-pilot differences with respect to task performance.

Due to circumstances beyond our control, the helicopter was detached from the Aeromedical Research Unit shortly after we had collected our pilot data and this research could not be completed.

It was demonstrated that:

- 1) Feasibility of instrumenting the helicopter for analog recording of outputs from the control surfaces.

- 2) Utilization of a hybrid computer system to process such data.

Because of the unavailability of a helicopter for further research we shifted to the instrumenting of an automobile (Chevrolet Sportsvan) during the second year of the contract, and further developed our techniques for recording visual search activity using electrooculographic techniques.

Again we were able to instrument the vehicle to our satisfaction and were able to record acceptable signals with a tape recorder (PI #6208). The tape recorder owned by our laboratory, an FR1300, did not prove to be a feasible recording device for field recording.

Our request for transferring funds into the equipment category was disallowed by the Preventive Medicine Research Branch, so this effort came to naught. Attempts at further data acquisition in the vehicle were abandoned and we restricted our work to the development of our eye movement data acquisition system.

The emphasis of our research effort for subsequent years was thus shifted from the area of performance assessment to the area of a) monitoring of visual search activity which is, to say the least, an important component of the task involved in piloting a helicopter; and b) the development of computer based data reduction procedures for the evaluation of visual search activity.

Both of these goals were met during the remainder of the contract period and two major studies designed, and to a large extent implemented.

I Development of Instrumentation Package for Recording Eye Movement.

The first instrumentation package developed in our laboratory utilized a recording system which was A-C coupled with a time constant of approximately 3 seconds. The system was developed for ease of operation in the aircraft with adequate gain and signal to noise ratio to allow us to record

the signals of interest. This system was utilized in our first study. Because we were interested in obtaining a better approximation to real eye position than was afforded by this system we had contract constructed a rather unique DC recording system. The system as finally built was a two channel DC recording system with a maximum gain of 2000. Since the recording characteristics of our tape recorders accept only a  $\pm 1.5\text{v}$  signal, and since the dynamic range of the signals of interest to us considerably exceeded this range, the system as finally designed has the capacity for automatic ranging as well as maintaining a record of the absolute voltage levels. It thus, like the AC coupled system, makes minimal demands on the operator once the subject is appropriately hooked into the system.

This recording system was utilized in our second experiment.

Because we were interested in developing a system for recording eye movement in the helicopter without physically attaching electrodes to the subject, we experimented with a capacitance plethysmograph developed by Dr. Stepan Figar of the Institute of Physiology, National Academy of Science of Czechoslovakia. The device works well in a laboratory setting but after experimenting with it for a number of months, we were unable to convert it to an acceptable field instrument. The system is exquisitely sensitive not only to the movements of interest to the investigator, but other motion as well.

## II Studies of visual search activity of helicopter pilots.

The first study dealt with the problem of comparing visual search activity in skilled and novice helicopter pilots as well as studying the effect of time-on-task on visual search activity. The task utilized was piloting a helicopter over a relatively simple fixed route. The results of this study are reviewed in the attached two publications. In summary, the

results of this study demonstrated:

1) Significant differences in amount of visual search activity between skilled and novice helicopter pilots for all aspects of the flight (take-off, in-flight, and landing). These results were most consistently observed for the horizontal eye movements.

2) Incidence of horizontal eye movements for skilled pilots are greatest during take-off.

3) Both skilled as well as unskilled pilots demonstrate decrements in visual search activity as a function of time-on-task. These effects are more strongly seen in the skilled pilot group ( $p .01$ ).

4) Both skilled as well as unskilled pilots spend significantly more time looking to the right side of their visual field than skilled pilots. This effect is more consistently found for unskilled than skilled pilots, and is probably due to their greater dependence on the copilot for information about the left side of the craft.

5) As a function of time-on-task pilots spend less time looking for "targets of opportunity" and restrict their visual search to patterned searching of (presumably) high density information areas.

All but the last of the above conclusions were generated from manually scored records and then verified by a computer based analysis.

The second major study proposed to investigate the effect of sleep deprivation on visual search activity of pilots while flying a proscribed course, as well as to evaluate the consistency of visual search activity of skilled pilots. The study as initially conceptualized was to collect data on 12 pilots at four different points in time, two prior to sleep deprivation and two following one night of such deprivation. Due to circumstances beyond our control (weather conditions at Fort Rucker during the data collection period), we ended up with half the data initially expected. Instead of having two sets of data for both the pre and post sleep depriva-



tion period, we ended up with one pre and one post sleep deprivation measure. Thus we were unable to evaluate our data for intra-pilot consistency effects. In addition the periods of time during which the pilot was in control of the aircraft averaged around 40 minutes and did not require the pilot to either take-off or land the vehicle. Thus the "stress" imposed on the subject by the task was considerably less than was true of our prior study. The results of this study were in general comparable to our earlier study. Significant effects, in the present study, were found for vertical eye movements while those in the horizontal were in the expected direction, but missed an acceptable level of statistical significance.

Additional findings from this study were:

- 1) For both horizontal and vertical plane eye movement data, there is a significant increase in variability between early and late in flight measures.
- 2) Sleep deprivation produces a decrease in such variability.
- 3) Eye blink closure duration was evaluated, and within subject comparisons made to evaluate the effect of sleep deprivation. For 6 out of 10 subjects a significant increase in long duration eye closures during eye blinks was found.

Both studies thus demonstrate the utility of recording visual search activity in a) the discrimination between skilled and novice pilots; b) in demonstrating decremental effects as a function of time-on-task; and c) in demonstrating effects of sleep deprivation.

### III Developments in computer based techniques for evaluating visual search activity.

Our current data reduction system utilizes a PDP-12/30 Advanced LINC

Computer. All analyses are conducted off-line but in Real Time and utilize analog tape recorded data. All programs developed allow for the monitoring of both the raw signal as well as the decisions made by the computer about such signals. This allows the human operator to remain intimately involved in the analytical procedure.

Our current library of programs allow us to perform the following analyses of visual activity.

- 1) EYEBLINK analysis.
  - a) identification of blinks
  - b) measure blink closure duration
  - c) measure interblink intervals
  - d) generate blink closure duration and interblink interval histograms
- 2) Horizontal plane activity.
  - a) identify saccadic eye movements
  - b) measure amplitude and direction of such movements
  - c) identify and classify patterns of eye movements
  - d) measure time between saccadic eye movements (fixation duration)
  - e) discriminate saccadic from other eye movements - such as pursuit or compensatory movements
  - f) generate summary data
- 3) Vertical plane activity.
  - a-f same routines as 2) above.
- 4) Concurrently analyze 2 and 3 above with time history to identify time of occurrence of events in both planes of movement.
- 5) Generate displays of eye movements in two dimensional space

with ability to delete (automatically as well as manually) portions of recording containing undesired information ("noise") such as eye blinks or other artifacts.

6) Generate 3 dimensional eye position displays in which the third dimension is time, the other two dimensions being eye position in the horizontal and vertical planes respectively.

7) We have developed a program to analyze a specific type of visual search activity - namely, eye movements during reading. This program identifies the following bits of information:

- a) time taken to read a line of print
- b) discriminate between saccadic eye movements associated with reading and return of the eye to beginning of a line
- c) identify and label saccadic eye movements (left and right going)
- d) measure duration of the saccad
- e) measure duration of fixation.

#### IV The analysis of visual search activity applied to reading.

Since the amount of data generated from our last experiment was no more than half the expected data, we (with concurrence of our contract monitor) initiated a study to evaluate the effect of time-of-day on some aspects of reading efficiency. The principal purpose of this initial study was to allow us to:

- a) develop the necessary computer programs to evaluate this type of visual search activity, and
- b) see if it was sensitive enough to pick up time-of-day effects.

In this study 11 volunteers came to the laboratory on two occasions (9 AM and 8 PM) and read short stories of their choice.

Analysis of reading activity.

The initial aim was the development of a computer program which would allow us to evaluate saccadic eye movements occurring during reading and to allow us to conduct a finer grained analysis of the reading process than was heretofore possible.

Justification for the development of this analytical process was based on some preliminary work which indicated that the process of reading was quite sensitive to drug effects (sedative) and the suspicion that it would be equally sensitive to other drug effects (tranquilizers, energizer, hallucinogen, etc.). The utilization of this task has many advantages over those commonly utilized in human psychopharmacological investigations. The principal ones are that it is a well learned task - so no time has to be spent in training the subject to perform the task, and it (dependent on the reading material chosen) is a task in which boredom does not mount as readily as is true of most of the tasks in the repertoire of most psychopharmacological investigators.

I. Computer program development.

Our programs for the analysis of visual search activity have been modified to allow us to measure what we believe to be some major aspects of visual activity during reading. Our program identifies saccadic eye movements to the left and to the right as well as those associated with shifting of the eyes from the end to the beginning of a new line. It further measures the amplitude of these eye movements as well as time taken for such movements.

The program further identifies duration of fixations (i.e. time between saccadic eye movements) and time taken to read a line. The current program analyzes the data in real time. The print-out of the above information is, however, a time consuming process. It takes approximately 20 minutes for the print-out of eye movements associated with three minutes of reading.

II. A simple experiment was modeled for generating data to allow us to evaluate whether significant changes in visual activity during reading occur as a function of time of day (AM vs PM) and to allow us to test some hypotheses associated with fixation durations at specified times during reading. For example, we hypothesized that fixation durations following a regressive eye movement should be of shorter duration than a forward going one.

Since our earlier pilot investigations produced data demonstrating that fixation durations are quite variable for the individual reader, rather than fluctuating within narrow limits for material of specified difficulty as suggested in the literature, we were especially concerned with the problem of identifying specific types of eye movements which might have contributed to the higher variability of fixation durations characterizing our data.

In the experiment, 11 subjects presumed to be adequate readers (all were graduate students in psychology or were beyond the Ph.D. degree) were asked to read a series of short stories at two points in time. They came to the laboratory at 9 AM and read for 45 minutes and then returned that evening at 8 PM to continue reading for another 45 minutes.

Visual activity during reading was recorded both on strip chart and magnetic tape with tape voice annotated for time. Every two minutes the experimenter identified time and other relevant information on the magnetic

tape.

Data reduction.

For each run three minutes of data were abstracted with the computer; early in the run (this usually consisted of minutes 3 to 6 of the reading period - both AM and PM) and three minutes late in the run (this usually consisted of minutes 40 to 43 of the reading period - both AM and PM).

A number of analyses of this abstracted data were conducted. The major ones dealt with changes in time to read a line as a function of time on task and time of day; and a fine grained analysis of fixation duration data regardless of time on task or time of day.

RESULTS.

(A) Time to read line analysis.

For each of the four sections of recording analyzed (early AM, late AM; early PM, late PM) we selected 35 lines of analyzed reading activity which met our criteria for acceptance as adequate data.

Two by two repeated measures analyses of variance were computed for each subject's data. A number of significant findings emerged, however, none were consistently found across all subjects. The one variable which was not significant for any subject was the AM early vs PM early comparison. For the AM-PM comparison the results were significant for one subject, for all other comparisons (early vs late, interaction term, AM-PM late, AM early vs AM late, PM early vs PM late) two subjects were found with results significant beyond the .01 level. Looked at another way, for 4 subjects, no significant effects were obtained while 7 subjects were significantly discriminated (beyond the .05 level) on at least one variable in the analysis of variance.

An across subjects analysis in which the thirty-five measures for each subject for each time period were combined, is depicted in figure 1. "t" tests for correlated means were computed for the four comparisons identified on the graph. There was a significant increase in average amount of time taken to read a line of print at the PM late measuring period. All other comparisons were not significant. The results of these analyses thus strongly suggest a decrement in reading performance which is best seen in the early evening. It appears that subjects' level of performance, as measured by average time to read a line, decays over the 45 minute PM reading period while no such changes are seen during the AM reading period.

(B) Analysis of fixation duration during reading data.

On the basis of pilot data in which we had found considerable variability in within subject fixation duration for forward going saccadic eye-movements, we felt that both these and regressive eye movements could be grouped into more homogeneous parcels.

A "logical" analysis of fixation patterns which occurred in a line of reading suggested the following breakdown of fixation durations:

- (1) Fixations which were part of the normal forward going (right moving) reading pattern.
- (2) Fixations associated in some way or other with regressive eye movements.
- (3) Fixations occurring at end or beginning of a line.

In the top portion of figure 2, we have graphically depicted the data utilized for specific analyses.

Pattern 1 - identifies forward going fixations with the exception of the first and last fixation on the line.

Pattern 2 - identifies fixation period associated with a regressive eye movement.

Pattern 3 - the fixation period immediately following a regressive eye movement.

Pattern 4 - the last fixation period on a line of print.

Pattern 5 - the first fixation period on a line of print if it is followed by a forward going fixation.

Pattern 6 - the first fixation period on a line of print if it is followed by a further deviation to the left.

Pattern 7 - the first right going fixation period on a line of print if it is preceded by a "further" left movement.

Pattern 8 - which was an afterthought and thus not fully analyzed in the present study - the fixation duration associated with the forward going saccade immediately preceding a regressive movement.

After appropriate editing of the analyzed data, the above measures were obtained for each subject. The number of data points on which this analysis is based range from a high of 1080 pattern 1 right moving saccades, to a low of 12 fixation durations for one subject involving pattern 7.

Figure 2 depicts the average fixation duration associated with each type of fixation as well as the variability (sigma) around the group mean.

Table 1 presents the analysis conducted on this abstracted data. Choice of groups to be compared was made prior to any analysis. It is readily apparent that right moving fixation durations associated with "normal" reading are significantly different from most of the other "patterns" of fixation duration identified. One word of caution (before we interpret these results) is necessary. For many "patterns" the within subject distribution of fixation durations was not normally distributed. We suspect



that in many cases the distributions are skewed and occasionally bimodal in nature. We are thus in the process of applying some non-parametric statistics to this data to further insure that the patterns we have identified are in fact unique and that their identification is necessary for fine-grained analysis of reading activity.

Our plans for the immediate future, should the proposed analysis substantiate the results depicted in figure 2 and table 1, is to generate the necessary computer programs to allow us to abstract the above information from our analysis.

#### DISCUSSION.

The results of our analysis of fixation duration associated with different reading demonstrates the utility of discriminating between different fixation patterns.

Let us, for the moment, presume that pattern 1 is associated with normal efficient reading, that is, we conceive of normal reading as a steady progression of right moving saccades with fixation periods defining the time necessary to abstract information before going on to the next "chunk" of information. The average fixation duration for this type of fixation is 242 milliseconds for our group of subjects with a standard deviation of 73 msec and a range of 124 to 421 milliseconds for the fastest and slowest readers, respectively. (The slowest reader had reading problems and dropped out of graduate school during the academic year.) Excluding him, the next slowest reader averaged 269 milliseconds for forward going fixations.

The second pattern concerned itself with regressive eye movements, i.e. fixation duration for the period immediately following a left going saccad. This fixation period is associated with going back to an earlier portion of the line (or page) and picking up a bit of information that was missed

earlier in reading, or for some other reason (some regressions are for confirmation, others are habitual, etc.). The average duration of these fixations was 189 msc (SD 53 msc). The range was from 86 to 298 msc, the latter figure again contributed by our slowest reader. These fixation durations are significantly shorter ( $p .01$ ) than those associated with our normal forward going movements. For all but one subject the average fixation duration associated with regressions to earlier portions of the line was smaller than fixation durations associated with forward going saccades. This, of course, suggests that less new information is taken in during fixations associated with regressive eye movements.

The third pattern concerned itself with fixation durations preceded and followed by right moving saccades where the immediately preceding saccad had been a left movement. Again, our suspicion was that such fixation pauses should be shorter than normal ones since there would, in general, still be overlap with material previously viewed. As indicated in table 1, fixation durations for this pattern are again significantly shorter than those for pattern 1.

Pattern 4 dealt with fixation durations immediately preceding return of the eye to the beginning of a new line. It was expected that such fixation durations would be more variable in duration than "normal" fixation durations. It was assumed that unless a subject adjusted fixation durations to take into consideration the length of the line of print to be read, that when he got to the end of the line, that the last fixation duration might be both longer, as well as shorter, than "normal" fixations. It is readily apparent from both figure 2 and table 1 that this expectation was not met. End of line fixations are neither more variable nor are they significantly shorter

or longer than "normal" fixations. This suggests that in "competent" readers the computer between the ear programs reading activity so that information intake is evenly distributed across the line of print for most forward going eye movements.

If one looks at fixation durations at the beginning of the line, a different picture emerges. These fixation durations are significantly longer than those associated with normal reading. Thus a subject either takes in more information at the beginning of the line than in later segments of the line, or, as we suspect, aspects of the return sweep of the eye to the beginning of the line are interfering and reducing normal processing speed.

Another possibility is that the eye movement to the beginning of a new line involves a sequential operation of first shifting back to the left side of the page and then shifting downward to get to the next line of reading material.

Pattern number six is associated with a specific type of reading inefficiency in which the eye, in its sweep from the end of a line to the beginning of a new line does not sweep back far enough and has to make a further saccadic eye movement to the left. Our expectation was that fixation duration associated with this movement should be shorter than normal fixation durations since the reader would only abstract partial information from the printed material before deciding that he had to go back to the very beginning of the line to make "sense" out of what he was reading. Our analysis demonstrates that fixation durations associated with this pattern are the shortest of all those identified and significantly shorter than those associated with our normal fixations.

Our suggestion that partial information is abstracted during this

fixation is borne out by the next analysis in which we evaluated fixation durations for fixation pause immediately following this left movement. Our expectation was that these fixation pauses should be shorter than normal ones since some of the material viewed during this fixation had been previously viewed. What was also to be expected was that this pattern would not be discriminated from pattern 3 in which we also looked at fixation duration associated with the eye movement following a regressive eye movement. The only difference between patterns 3 and 7 was that the latter occurred at the beginning of a line while the former could occur at any position except the beginning of a line. As depicted in table 1, fixation duration for pattern 7 is significantly shorter than that for normal reading (pattern 1) and not differentiated from pattern 3.

We thus end up, in the current analysis, with five eye movement patterns associated with fixation durations which discriminate them from normal forward going saccades and fixation durations associated with them. This analysis thus strongly suggests the importance of identifying patterns of eye movements during reading which should be discriminated in reading diagnostics.

V An excursion into capacitance plethysmography.

As indicated earlier in this report, I spent some time (in Dr. S. Figar's laboratory) attempting to utilize capacitance plethysmography for the recording of eye position data. In addition, I learned his techniques for utilizing this device for the recording of both peripheral vascular activity as well as vascular activity from the temporal artery (supplied by the external carotid), and the ocular artery (supplied by the internal carotid). These techniques are used in the clinical neurology laboratory for diagnostic purposes and appear to be useful techniques that deserve investigation by American neurologists.

In general, patients with various neurological problems - such as migraine, psychomotor epilepsy - demonstrated paradoxical responses (peripheral vasodilation and temporal artery vasoconstriction), as well as responses unique to their particular disturbance. Some work, which appears to be most promising, are investigations of bilateral asymmetry of functioning as a function of problems such as stroke, unilateral migraine, etc.

VI Utility of our research to operational problems.

A. Though circumstances beyond our control did not allow us to complete our research on the output of the manipulanda utilized by the pilot, or to allow us to investigate a similar problem in a motor vehicle, we are still convinced that such measures will be useful in

- a) the assessment of proficiency and
- b) the monitoring of possible decrements in performance as a function of such variables as time on task, level of stress, and fatigue,
- c) the development of performance criteria for tasks such as flying a helicopter.

B. Visual search measure.

We believe that measures of visual search activity, and the development of computer based techniques for the evaluation of such activity should be vigorously researched. The utility of these measures lies less in their direct application to the operational field situation than in their utility as

- a) further criterion measures for the development of more peripheral criterion measures (such as those outlined in A above)
- b) training devices - to give the pilot and pilot instructor feedback about the adequacy with which the pilot searches his environment.

For example, both student pilots and to a lesser extent skilled pilots concentrate their visual search activity to the right side quadrants of the vehicle, presumably leaving the left side to the copilot.

A second application as a training device would be in the use of this information as a bio-feedback device.

c) If, as we suspect, aspects of the eyeblink (especially closure duration) is a sensitive indicator of inefficient performance, it then seems feasible to develop some simple sensing devices and use this type of information in the field situation.

The visual search measures associated with reading performance need further development but appear promising for a wide variety of investigative efforts ranging from psychopharmacological investigations at one extreme, to their possible application in the teaching of skills necessary for the development of reading skills, and improvement of such skills.

FIGURE 1.

-20-

$\bar{X}$  TIME TO READ A LINE  
in SECONDS

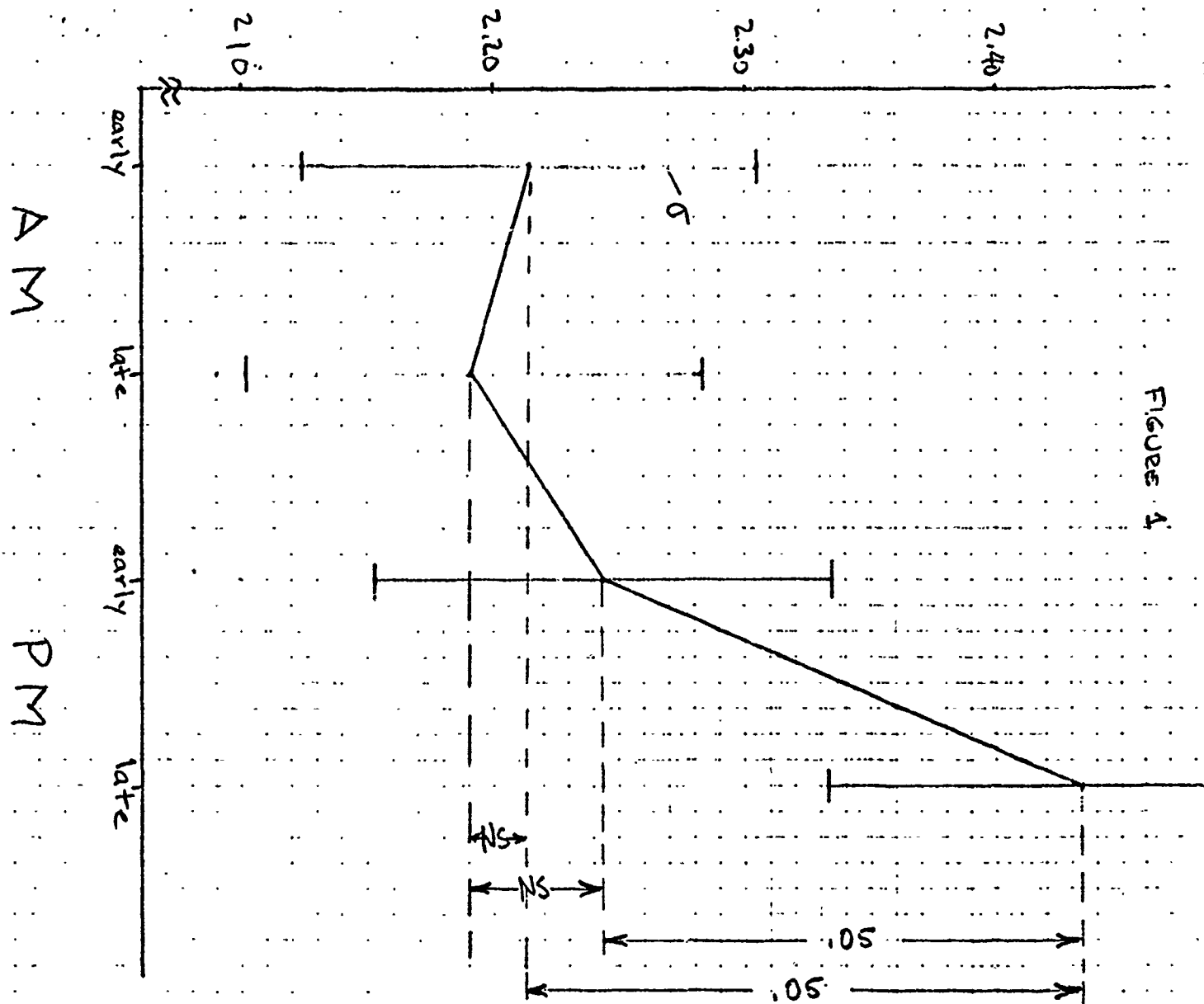


FIGURE 4

## ANALYSIS of FIXATION DURATION - READING.

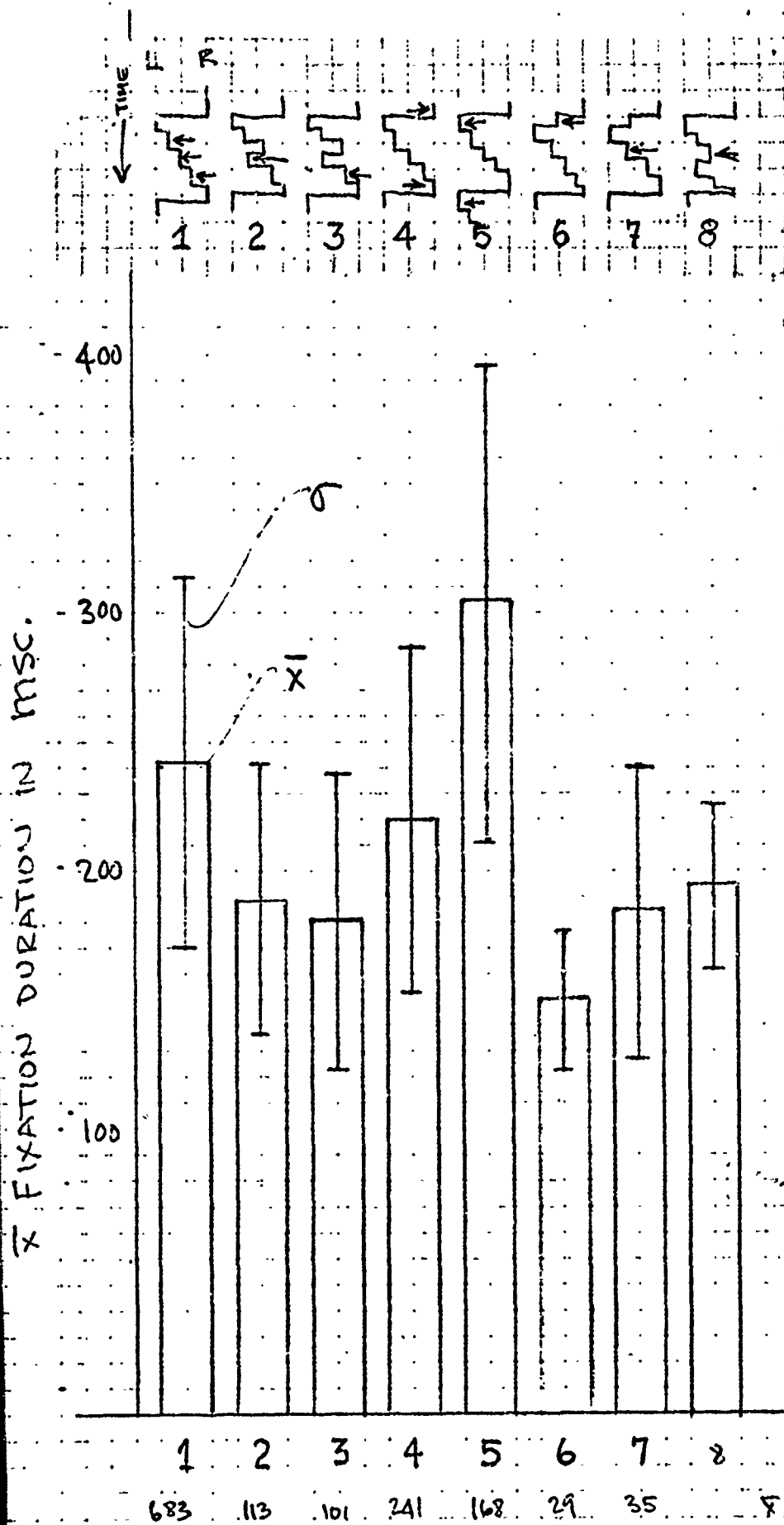


TABLE 1

"t" tests for correlated  $\bar{x}$ 

GROUPS COMPARED	df	t	p
1-2	10	4.41	.01
1-3	10	3.46	.01
1-4	10	1.85	NS
1-5	10	5.52	.001
1-6	10	4.93	.001
1-7	9	2.79	.02
1-8	9	3.20	.02
2-6	10	2.88	.02
4-5	10	5.09	.001
3-7	9	1.01	NS
5-7	9	4.58	.01

$\bar{x}$  observations per subject  
on which results are  
based.



Final Report, Contract DA 49 193 MD 2715

PERSONNEL	PERIOD ON GRANT	DEGREE
B. J. Abernathy	2/1/68-6/30/68	M.S.
R. Buckhout, Ph.D.	6/16/65-6/15/66	(Staff) -
J. C. Burton	7/1/65-6/30/72	(Staff) -
C. K. Chen	9/1/71-6/30/72	(Staff) -
S. C. Chen	9/1/69-5/31/71	M.S.
J. A. Clizbe	6/16/65-9/15/65	-
A. G. Conway	7/1/68-6/30/72	(Staff) -
V. A. Cox	7/1/66-6/30/67	(Staff) -
P. A. DiNardo	9/16/68-6/30/69	-
R. Goldstein, Ph.D.	1/1/66-5/31/67	(Staff) -
T. P. Grace	9/15/65-1/31/66	-
S. G. Offenbach	2/1/66-9/14/66	Ph.D.
J. A. Stern, Ph.D.	6/1/68-6/30/72	(P.I.) -
M. E. Troy	7/14/69-10/31/71	-
E. Wolfersberger	7/1/66-9/30/66	(Staff) -

1965-1972

Bibliography  
of  
Publications

Bynum, J. A. and Stern, J. A. Painted helicopter main rotor blades and flicker-induced vertigo. Aerospace Medicine, 40(6), June, 1969, 622-626.

Stern, J. A. and Bynum, J. A. Analysis of visual search activity in skilled and novice helicopter pilots. Aerospace Medicine, 41(3), March, 1970, 300-308.

Troy, M. E., Chen, S. C. and Stern, J. A. Computer analysis of eye movement patterns during visual search. Aerospace Medicine, 43(4), April, 1972, 390-394.

# Painted Helicopter Main Rotor Blades and Flicker-induced Vertigo

JAMES A. BYNUM and JOHN A. STERN

U. S. Army Aeromedical Research Laboratory, Ft. Rucker, Alabama 36360, and Department of Psychology, Washington University, St. Louis, Missouri 63104

BYNUM, J. A., and J. A. STERN. *Painted helicopter main rotor blades and flicker-induced vertigo*. *Aerospace Med.* 40(6): 622-626. 1969.

Painting the main rotor blades of UH-1 helicopters led to the question of the possibility of flicker-induced vertigo in formation flights involving these helicopters. Two experiments were designed to answer the question. In the first, thirty students and eight instructors flew in formation flights consisting of helicopters with painted rotor blades. Immediately following the flights their subjective responses were obtained and evaluated. In the second experiment, ten students were screened from a group of thirty-seven on the basis of psychophysiological data and subjective responses to laboratory photic stimulation. Seven of these ten then flew in formations while EEG, EOG, and eye blink data were recorded. Subjective evaluations were also obtained immediately after the flights. There were no indications in either experiment to indicate the painted blades as a source of flicker vertigo.

**R**ECENTLY THE U.S. Army Aeromedical Research Laboratory was asked to participate in a program of reducing mid-air collisions. A review of the problem suggested that lack of conspicuity of the helicopter was one important component leading to mid-air collisions. The initial problem evaluated dealt with making the helicopter more conspicuous. For obvious reasons conspicuity was restricted to seeing the helicopter from above. Research<sup>1,2</sup> by USAARL on the visibility problem led to the recommendation that a specified pattern of paint be applied to the upper surface of the main rotor blades of helicopters to enhance their visibility from above.

Since this program was to involve all training helicopters at the Aviation Center, the question was raised as to the possibility of adverse effects from the rotating painted blades. The specific effect of concern was photic stimulation induced "flicker vertigo". To this point, research involving photic stimulation in fixed wing aircraft and helicopters<sup>3,4,5,6</sup> has dealt with flicker disturbances as a function of interrupted light coming through either the blade or the propeller, but none was found

indicating concern with flicker from sources away from the aircraft in which the pilot was flying. The situations dealt with so far have involved investigations of various light-dark ratios caused by the rotor blade or propeller of the aircraft in which the pilot was flying.

The apprehension expressed regarding the present problem was couched in terms of "flicker vertigo" being produced by observation of painted rotor blades. Vertigo, of course, has several connotations. It may result from vestibular stimulations, visual stimulations, or both. The technical definition of the sensation of vertigo indicates that there is more than one cause for vertigo, and more than one kind of vertigo.

The problem of concern here was obviously visual in nature since it was expressed in terms of the possibility that a painted rotor system could stimulate the pilot in such a way as to cause spatial disorientation or other dysphoric sensations. This research, therefore, operationally defined vertigo as a flicker-induced phenomenon which causes adverse effects as a result of viewing painted main rotor blades from above in formation flights.

In order to investigate this problem, a design was conceived which would relate certain psychophysiological responses to photic stimulations under the assumption that the effects (flicker vertigo) would be indicated by recordings of these parameters. Other research<sup>1,2,7,8,10,11</sup> has centered on the relationship of flicker to electroencephalographic (EEG) changes and suggested the utility of the EEG in this regard.

It was implicit in this approach that there was some relationship between photic stimulations and flicker-induced vertigo such that an individual who demonstrated susceptibility to photic stimulations in the laboratory should be a good candidate to test for the possibility of flicker-induced vertigo in a helicopter. Consequently, two experiments were designed to answer the question of whether the viewing of painted blades produced sensations of vertigo.

In the first experiment, subjective data were gathered from a random sample of instructor and student pilots. This sample was divided so that one group of aviators was administered photic stimulations in the laboratory and the second group was not. Then both groups were

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

flight-tested and information was compared, both with the subject as his own control and between subjects.

The second experiment incorporated the more objective psychophysiological data as well as some subjective data. The overall design for this experiment was to administer photic stimulation to a random sample of students and record their EEG, EOG, eye blinks and subjective responses. A select number were then flown in formations of helicopters with painted rotor blade and comparisons were made using subjects as their own control and between subjects.

## EXPERIMENT 1

### Materials and Methods

Thirty students and eight instructors were randomly chosen as subjects. Six students and four instructors were selected from this group and given a laboratory orientation about flicker, the problem under investigation, and their role. This group was designated Group E (experienced). The remaining twenty-eight subjects were designated Group N (naive) because they were given no advanced information prior to their flights in a formation containing the painted rotors.

Two duty days preceding the week in which Groups N and E were scheduled to receive their first instructional periods in formation flying, Group E subjects reported individually to the laboratory for an orientation. During an interview, each was asked about his concept of vertigo and most responses alluded to spatial disorientation.

Each subject was then seated in a dimly lit room and instructed to look at the center of a translucent plastic screen placed 12 to 18 inches in front of his face. He was then told to expect to see a flickering light and was asked to relate aloud any sensations as they were experienced. The subject was then stimulated with flickering lights at 7 cps, 10 cps, and 14 cps produced by a slide projector and attached episcope. Frequencies were chosen to correspond with the UH-1 Helicopter rotor blade which turns at approximately 10 cps (considering both blades).

After stimulations, each subject was debriefed and asked specifically about dysphoria, experience of colors, nausea and other symptoms of illness. Subjects reported sensations ranging from dizziness to dysphoria and each subject was sure he would be able to recognize such sensations, should similar photic stimulation occur in other situations.

For the flight tests, subjects flew in "V of Vs" and "Staggered Trail" formations and were positioned at a variety of locations during the period. Thus each was stimulated by the blades at several angles and distances.

Upon completion of a flight period lasting about 1 hour, each S was interviewed and debriefed. The following questions were asked and answers were recorded verbatim:

1. What did you think about the flight?
2. As you watched the rotors, did you notice any sensations that were peculiar? Any like those experienced in the laboratory? (Group E only)

3. Did you have any unusual difficulties with your eyes? In other words, were there any unusual problems with your eyes that you have never had before?
4. Did you notice any unusual muscle activity around your head or any part of your body?
5. What about any general symptoms of illness? Did you notice any problems there?
6. What is your personal opinion of painting the rotor blades? Do you think it helps you see the aircraft any better?
7. How did you like the blades when you first saw them? What do you think of them now that you have flown in formations with them? why?

### Results and Discussion

Table I indicates the technique by which responses were judged. This table, abstracted from a comprehensive report on flicker,<sup>1</sup> seemed a promising way to assess results.

On the basis of the table, each response was scored as zero which indicates no adverse responses. None of the thirty-eight Ss interviewed reported any sensations that were peculiar. There were no reports of unusual difficulties with the eye nor were there any reports of unusual muscle activity. No S reported any symptoms of general illness.

TABLE I. CLASSIFICATION OF EFFECTS

A Effects:	Hypnotized — strange — panic — disturbing — dizzy — hazy — woozy — pass out — head heavy — mind blank — can't concentrate — drowsy — loss of orientation — balance — paralyzed — eyes functionless.
B Effects:	Eye fatigue — eye sting — watery — eyes hurt — pressure on eyes — eyes wandering — pain.
C Effects:	Blinking — face and eyes twitching — violent or driven blinking — jumping (with light) — hard to keep eyes open — head and jaw muscles pulsating with light.
D Effects:	Headache — tense — nausea — queasy — chills up and down spine — turning in pit of stomach — muscles tense in back of neck.

0 = No adverse response					
	1	2	3	4	5
	Anticipatory	Slight Effect	Moderate Effect	Moderate Large Effect	Extreme Effect
A Effect	"	mind blank can't concentrate drowsy	strange head heavy disturbing	panic loss of orientation balance enclosure	hazy pass out hypnotized dizzy woozy paralyzed eyes functionless
B Effect	"	slight eye fatigue	eye fatigue pressure on eyes eyes wandering	eye sting sore irritated pain	eyes watering
C Effect	"	blinking eyes twitching	fast blinking hard to keep eyes open	driven blinking jaw muscles pulsating with light (head)	violent jumping face twitching
D Effect	"		bad feeling queasy turning in pit of stomach	headache muscles tense in back of neck	nausea chills up and down spine

All Ss indicated a favorable opinion in response to Question 6. Each S expressed the opinion that the paint did make the aircraft easier to see.

Question 7 was aimed at obtaining Ss' impressions of their first encounter with the painted blades and how these impressions compared with a prolonged (1 hour) encounter. All Ss reported favorable impressions on first seeing the blades and further contact did nothing to alter these impressions.

Several related comments should be noted. Ss indicated that, in some instances, the painted blades were perceived as an asset in formation flights. These comments were based on opinions that flight attitudes of the lead helicopters were more easily detected, especially rolling in and out of turns, because of a noticeable change in the plane of the rotor disc.

There were no reports of a "compelling urge" to stare at the rotor systems. This is probably due, in part, to the instructions each student receives on correct sight pictures in formations.

Special reference should be made to the responses of Ss in Group E. None reported any sensations similar to or remotely resembling those reported in the laboratory.

Dichotomizing responses into those from instructors versus those from students yielded essentially the same information, that is, there were no indications of adverse effects as a result of painted rotor induced "photoc stimulation" while flying in formations.

### Conclusions

As a result of the subjective data, the following conclusions were reached:

1. There were no adverse effects from flying in formation of helicopters that had painted main rotor blades.
2. Subjects given a pre-test orientation to photic stimulation performed no differently than Ss who were naive with regard to the painted blades.
3. The painting of helicopter main rotor blades has some values secondary to conspicuousness. Painted blades appear to serve as an aid in judging accelerations, decelerations, flight attitude and relative position.

## EXPERIMENT 2

### Materials and Methods

Thirty-seven student pilots were randomly selected to serve as subjects for the laboratory recordings. On the basis of their EEG activity and subjective responses to photic stimulation, ten of these were then selected to participate in the flight phase.

The same photic stimulation apparatus described in Experiment 1 was used in this experiment. A Grass Model 5 Polygraph was used to record two channels of EEG, one channel of eye movement in the horizontal plane, one channel of eye blinks, one channel of photic stimulation and one channel of time code information. An Ampex DAS 100 data acquisition system was coupled with the Grass recorder so that magnetic tape

recordings were made concurrently with the ink tracings. Calibration signals for the EEG recordings were provided by a Wavetek multi-purpose VCG 116 signal generator. A photocell was used to monitor frequency of photic stimulation. During the airborne phase of the experiment, a specially fabricated pre-amplifier system was used, and the output from the amplifier system fed into an Ampex AR 200 airborne tape recorder system.

During the laboratory recording sessions, standard silver disc electrodes were used for EEG signals and Beckman Bio-Potential electrodes were used for EOG and eye blink recording.

Subsequent to data recording, the EEG data were edited and one channel was then processed through a computer system consisting of a series of twenty band-pass filters with output of each filter integrated over a ten-second period. Integrated data were then converted from analog to digital form and further processed on a PDP-5 digital computer. The final output included a printout of the output of all filters for up to 10 periods of analysis, the mean value and standard deviation for these 10 periods and a measure relating energy at any one frequency to the total energy.

Subjects reported to the laboratory, individually, and each was given a brief orientation to the problem and his role. Electrodes were then attached to the outer canthus of each eye and above and below the orbit of the right eye. Parietal-to-occipital electrodes were attached on both sides of the head for EEG data and the subject was grounded at the ear lobe. Ten K ohms resistance or less was deemed acceptable for all leads. The subject was then placed in the recording room as described in Experiment 1.

EOG and eye blink recordings were made, using the Grass P51C low level DC preamplifier. A time constant setting of 0.8 was used and sensitivity was set at 0.2 millivolts per centimeter. EEG recordings were made with a Grass Model 5P5E EEG preamplifier. Sensitivity was set at 30 microvolts per centimeter with 60 cycle filters in.

After eye movement direction had been established and the subject was seated and comfortable, he was asked to close his eyes and relax. A calibration signal of 10 cycles per second was fed into the EEG leads for a 45-second period prior to the actual test run. All calibrations and eye movements were recorded both on the ink written tracing and the magnetic tape.

The actual test run was conducted in the following manner. Two minutes of eyes closed resting recordings were made. Subject was then directed to open his eyes and two minutes of eyes open rest were recorded. At the end of this two-minute period, the photic stimulation was introduced. Two minutes of stimulation at each of four frequencies was recorded. Frequencies were 7, 10, 14 and 28 cps. The output of the photocell was recorded on the ink written tracing as a check on frequency. Following each two-minute period of photic stimulation, the light source in the stimulator was turned off and the experimenter entered the room and asked the subject what he experienced at that time. Subject's responses were recorded verbatim. Following the 28-

cycle stimulation, the photic stimulator was turned off and S was directed to sit with eyes open and two minutes of eyes closed resting recordings were made and then another 45-second calibration signal was fed into the EEG leads.

The two prime considerations for selecting ten subjects from the original group of thirty-seven were EEG activity and subjective responses. Five subjects were selected from the group because they demonstrated clearly defined EEG photic driving responses and five subjects were selected because they reported dysphoric sensations when subjected to the photic stimulations. This group of ten subjects was further tested in the flight phase. Further discussion of these results is contained in the Results and Discussion section.

Because of certain administrative problems, three of the ten Ss were eliminated from the testing. This left seven Ss for the flight tests. For the flight recordings, all leads were located in the same positions and in the same manner with the exception of the EEG leads which were placed on the scalp with Grass electrode paste and collodion to allow the pilot to wear his protective helmet during data collection procedures.

The airborne recordings were made during actual tactical training maneuvers in formation flights with student pilots at the controls. There was no opportunity to manipulate variables such as altitude, heading, location, etc., and the only manipulation allowed was whether the pilot was in the formation with the other aircraft or was withdrawn from the formation and therefore flying single ship maneuvers. Each flight lasted approximately 50 minutes and consisted of formation flying and solo flying. Data reduction techniques for both the laboratory and the airborne phases were outlined in the Apparatus section.

### Results and Discussion

The incidence of dominant alpha activity was unusually high in this population. Under eyes closed conditions, 88 percent of the subjects demonstrated good alpha (defined as energy in any one band in the alpha range being greater than 10 percent of the total energy in the bandpass filter system). Such a high amount of alpha activity is unusual, especially in the first recording of EEGs.

Under both eyes open and eyes closed conditions, we found subjects who developed drowsiness as measured by reduction in alpha frequency from the pre to the post photic stimulation run. What is, at first glance, surprising is the complete lack of overlap between those who demonstrate this phenomenon under eyes open conditions as compared to eyes closed conditions. An explanation for this discrepancy is not readily forthcoming. Utilizing either condition, we find approximately 25 percent of our subjects developing some signs of sleep inhibition.

Utilizing a more stringent criterion of "sleep inhibition", namely, a decrease in the dominant alpha frequency coupled with a general increase in energy at the lower frequencies, we find that seven out of eight subjects identified by the previous criteria are still so identified. The four frequencies below the alpha band,

4, 5, 6 and 7, and the four adjacent frequencies above the alpha band, 13, 14, 15 and 16, were evaluated with respect to shift and the percent of energy at each of the above center frequencies. Since we are concerned with the evaluation of drowsiness or fatigue as a function of exposure to photic stimulation, it was predicted that drowsiness would be accompanied by an increase in percent of energy found in the low frequency bands and a decrease in percent of energy in the beta one band (13 to 18 cps). Evaluation of the data demonstrated that three things could occur, a decrease in percent energy at a given frequency when comparing the post to the pre photic stimulation record, an increase in percent energy, or no change in percent energy. Using as a crude criterion of "drowsiness" that the number of frequencies at which the predicted change exceeded changes in the direction of greater alertness by at least two (out of a total of eight), we find that under the eyes closed condition eight out of seventeen subjects demonstrated an increase in drowsiness while three became more alert. Under eyes open condition, five out of fourteen subjects demonstrated an increase in drowsiness and three an increase in alertness. We thus have suggested evidence that photic stimulation produces more of a shift toward drowsiness than toward alertness.

Of the thirty-seven subjects evaluated, fifteen experienced no discomfort or unusual experience in response to photic stimulation. Nine experienced hypnagogic effect such as a feeling of sleep and drowsiness, relaxation, daydreaming and feeling of euphoria. Fifteen subjects experienced discomfort of one type or another. Specifically, they reported sensations of annoyance, irritation, eyes hurt, headache and soreness of eyes, difficulty keeping eyes open, loss of depth perception, distractions, sensation of feeling themselves moving or floating, and sensations of vertigo, nausea and dizziness. Thus more than half the subjects experienced some type of dysphoric sensation.

Whether the experiencing of dysphoric sensations with photic stimulation can be generalized to other situations such as helicopter flying seems a distinct possibility. If dysphoric sensations such as vertigo are experienced frequently enough by helicopter pilot trainees to be a source for disqualifying them from further flight training, a study relating these two phenomena—vertigo while flying and dysphoric sensations produced by photic stimulations—should be conducted with the aim of using the response to photic stimulation as a prediction of sensing disturbances during flight training.

An analysis of the data collected in flight showed the EEG records to be minimally useful, due to a high incidence of artifact in the recordings. The major contribution to this artifact was attributed to the helicopter vibration producing electrical noise in the EEG amplifiers. Where data was adequate for evaluation, no signs of any abnormal EEG activity were detected. Eye movement and eye blink recordings were collected on six subjects. For four subjects, adequate signals for the concurrent analysis of both eye movement and eye blinks were obtained. Though we have no external

# PAINTED HELICOPTER BLADES & FLICKER-INDUCED VERTIGO—BYNUM & STERN

criteria, we were impressed by a number of aspects of the data. These were:

1. The lack of visual scanning by the pilot;
2. The reduction in scanning rate as a function of time on task;
3. Reduction in degree of movement with a given saccad;
4. Reduction in blink rate as a function of time on task; and
5. Impairment in visual activity as measured by the relationship between saccadic movement and eye blinks.

## Conclusions

On the basis of this experiment and Experiment 1, the following conclusions, recommendations and observations are relevant:

1. Photic stimulation effects, as experienced in the helicopter, do not constitute a major problem with respect to the development of flicker-induced vertigo. Dysphoric sensations due to photic stimulation occur only under special conditions in the aircraft.
2. The EEGs of our subjects demonstrate markedly more alpha activity than is characteristic of similar groups of young men not on flying status.
3. The effect of photic stimulation on resting EEG activity is such that:
  - (a) Subjects seemed to demonstrate one or more signs of a decrease in alertness when comparing the pre and post photic stimulation recordings;
  - (b) Some subjects demonstrate either no change in alertness or a post photic stimulation increase in alertness; and
  - (c) It thus appears that pilots are differentially affected by photic stimulation.

Interestingly, those reporting sensations of drowsiness or sleep in response to photic stimulation were not necessarily the subjects who demonstrated electroencephalographic evidence of drowsiness.
4. Subjective sensations in response to photic stimulation identified that nine out of thirty-seven experienced hypnagogic phenomenon and fifteen

discomfort while being stimulated in the laboratory.

5. Eye movement and eye blink data collected in flight suggest that these measures may have considerable utility in evaluating adequacy of flight performance as well as a measure of task-induced fatigue.
6. Helicopters with a symmetrical paint design on the upper surface of the main rotor blade did not interrupt the normal operations of the student pilots. Psychophysiological data and subjective data did not indicate the paint to be a source of flicker-vertigo.

## ACKNOWLEDGMENTS

Table I was used with the permission of L. M. N. Bach.

## REFERENCES

1. BACH, L. M. N.: (Ed.) ERDL—Tulane Symposium on Flicker. ASTIA AD 155440, April, 1957.
2. BACH, L. M. N., C. J. SPERRY, JR., and J. T. RAY: Tulane studies on the effects of flickering light on human subjects. in L. M. N. Bach (Ed.) ERDL—Tulane Symposium on Flicker. ASTIA AD 155440, April, 1957.
3. BYNUM, J. A., R. W. BAILEY, J. K. CROSLLEY and M. S. NIX: Development of a paint scheme for increasing helicopter conspicuity. USAARU Report 68-1, September, 1967.
4. CARPENTER, R.: Flicker vertigo. *Flight Safety Foundation Pilots Safety Exchange Bulletin* 55-110. November 30, 1955.
5. CROSLLEY, J. K., R. W. BAILEY and M. S. NIX: Improving helicopter conspicuity through the use of painted main rotor blades. USAARU Report 68-2, October, 1967.
6. JOHNSON, L. C.: Flicker as a helicopter pilot problem. *Aerospace Med.* 34:306-310, 1963.
7. JOHNSON, L. C., G. A. ULETT and G. C. GLESER: Studies of the photically simulated EEG—Quantification and stability of photic driving patterns. *School Aviation Medicine USAF Report* 57-54, 1957.
8. STERN, J. A.: Photic stimulation—the activation response simulated helicopter photic stimulation—EEG activation and subjective sensation. Final Report, U. S. Army Medical Research and Development Command Contract DA-49-193-MD-2179, September, 1965.
9. ULETT, G. A.: Flicker sickness. *AMA Arch. Ophthalmol.* 50: 685-687, 1953.
10. ULETT, G. A., and G. GLESER: The effect of experimental stress upon the photically activated EEG. *Science* 115: 678-682, 1952.
11. ULETT, G. A., and L. C. JOHNSON: Pattern, stability and correlates of photic-electroencephalographic activation. *J. Nervous & Mental Diseases* 126:153-168, 1958.



# Analysis of Visual Search Activity in Skilled and Novice Helicopter Pilots

JOHN A. STERN and JAMES A. BYNUM

Department of Psychology, Washington University, St. Louis, Missouri 63104

STERN, J. A., and J. A. BYNUM. *Analysis of visual search activity in skilled and novice helicopter pilots.* Aerospace Med. 41(3):300-305. 1970.

Eye movements in both the horizontal as well as vertical plane and eye blinks were recorded in 13 skilled and 13 unskilled pilots while flying the UH-1D helicopter during a cross-country flight of approximately 50 minutes duration. Saccadic eye movements in both the horizontal and vertical plane were evaluated. The results demonstrate that skilled pilots engage in significantly more visual search activity in the horizontal plane than is true of novice pilots. Both skilled and unskilled pilots demonstrate changes in visual search activity as a function of time on task. These changes include: a decrease of searching in the horizontal plane; a decrease in searching in the vertical plane; an increase in the amount of time not engaged in search activity per unit time; and a decrease in blink rate. These results are interpreted as suggesting a decrease in visual search activity as a function of time-on-task.

This research was supported by Department of the Army Contract No. DA 49 193 MD 2715, and conducted through the active cooperation between the contractor and the U.S. Army Aeromedical Research Unit at Fort Rucker, Alabama.

Dr. Stern is professor of psychology, Department of Psychology, Washington University, St. Louis, Missouri 63130.

Dr. Bynum is now at Institute of Contemporary Corrections and the Behavioral Sciences, Sam Houston State University, Huntsville, Texas 77340.

A LARGE COMPONENT of the skills necessary for flying a helicopter involves visual activities. These activities usually include looking for landmarks, etc., to maintain some desired ground track, scanning instruments, and searching for other aircraft. In a previous study<sup>1</sup> involving student helicopter pilots, we were disturbed by the fact that student pilots appeared to engage in very little visual searching outside the aircraft when compared with the visual search activity of skilled pilots. Visual searching was, in this instance, evaluated by observing head movements of pilots from a position directly behind the pilot.

The current study is an attempt to evaluate this "clinical" observation and to objectify and extend these observations. The specific hypotheses we set out to test were: (1) unskilled pilots will engage in significantly less visual search activity than is characteristic of skilled pilots (training effect); and (2) visual search activity will decrease as a function of time on task (fatigue effects).

## PROCEDURE

**Subjects**—Two groups of subjects were utilized with 14 subjects per group. The skilled pilot group was composed of pilot instructors at Fort Rucker as well



# VISUAL SEARCH ACTIVITY IN HELICOPTER PILOTS—STERN & BYNUM

as pilots who had recently returned from a tour of duty in Viet Nam and had considerable experience in piloting the UH-1D helicopter. Student pilots had been through basic helicopter flight training and were at time of testing in the early stages (2nd or 4th week) of transition training on the UH-1D. Due to equipment malfunctioning, data for one subject in each group were lost (No pilots or aircraft were lost!). The analyses to be reported were thus based on 13 subjects per group.

**Instrumentation**—(a) Subjects were instrumented with Beckman bio-potential electrodes, one electrode each was attached at the outer canthus of the left and right eye, one electrode immediately below the right eye and one immediately above the right eyebrow. For horizontal eye movement recording the potential difference between the two electrodes on the outer canthus of the eyes were recorded. Vertical eye movement and eye blinks were recorded across the remaining two electrodes.

(b) The potential difference for these two sets of leads were appropriately amplified by two battery operated special purpose amplifiers manufactured by Diginetics Inc. (Bridgeton, Missouri). A third amplifier for recording voice communication in the helicopter and for annotation of the tape recording was also utilized.

(c) The output of these amplifiers were recorded on an airborne tape recorder (AMPEX AR 200) with inputs monitored on a portable oscilloscope. Biological signals were recorded through FM record amplifiers at a tape speed of 3% i.p.s.

(d) Calibration signals incorporated in the R-J signal conditioning equipment, were laid down on tape at the beginning of each data run.

(e) At the beginning of each subject run he was asked to look at various specific sites in the cockpit and eye movements during these activities recorded. Sub-

jects were asked to look to left and right without moving their heads, to move their heads to left and right, to look at the instrument panel (in front of and below their normal line of sight), to look at the radio (to left and below normal line of sight), to look at top of window and to blink their eyes five times.

(f) Tape recorded data were brought back to the laboratory, a time code was laid down on one of the spare tracks of tape and both the raw signals and time code strip charted at a paper speed of 12 mm/sec.

All subjects participated in similar flight plans. At the start of the run and after electrodes had been applied and the data recording system checked out, the pilot was instructed to hover the aircraft over a fixed spot for a 2-minute period. He then proceeded on the flight plan which consisted of a cross-country flight lasting approximately 50 minutes. The pilot then landed the helicopter and again hovered the aircraft over a fixed spot before the recording was terminated.

## RESULTS

Figure 1 depicts eye movements recorded when a subject was instructed to make specified eye and head movements. In all cases the upper tracing reflects eye movements recorded in the horizontal plane, the lower tracing eye movements recorded in the vertical axis with associated eye blinks. Instructed to look to the left without moving his head, the upper tracing deviates in an upward direction with a minimal upward shift in the lower tracing. The drift of the pen toward the zero position observable in this recording is not a function of the subject's gaze returning toward center (he was instructed to look to left and keep eyes in the directed position until instructed to return gaze to cen-

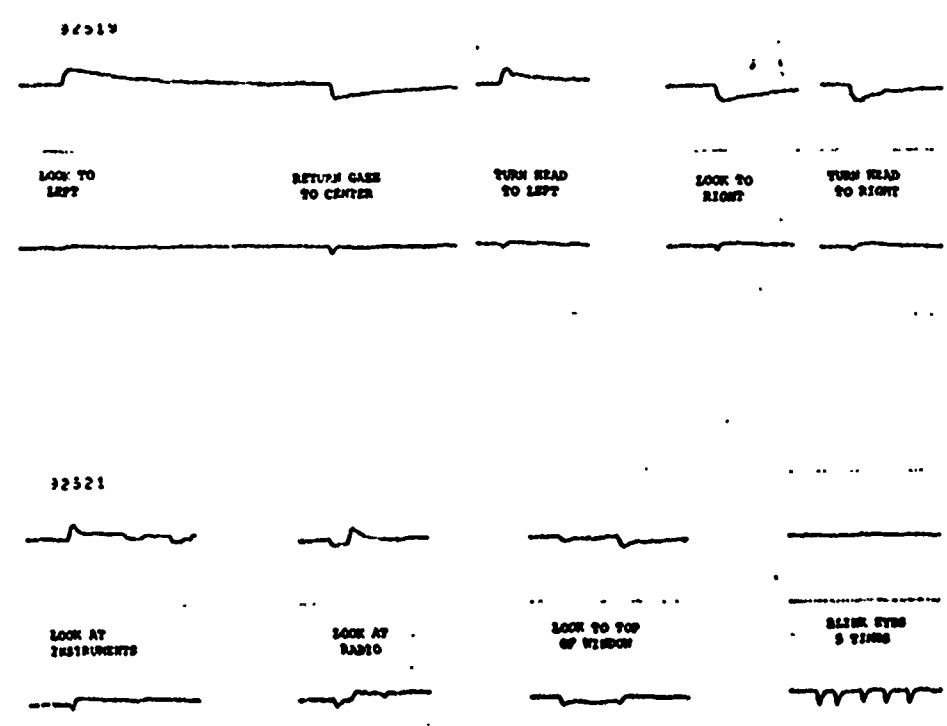


Fig. 1. Visual activity in response to specific instructions. Upper line—eye movements in horizontal plane. Lower line—eye movements in vertical plane and eye blinks.

# VISUAL SEARCH ACTIVITY IN HELICOPTER PILOTS—STERN & BYNUM

ter) but a function of the time constants built into the amplifiers (1.5 sec.). When asked to return gaze to center, voltage deviation is in the opposite direction and the subject blinks in association with the shift in gaze. In the next three segments of recording, eye and head movements are all associated with an eye blink. The eye blinks are involuntary (i.e., not requested by the examiner). Instructed to look at the instrument panel we see, in the lower line, an eye blink associated with initiation of the response and the subject looking downward. In addition, the upper tracing of the pair demonstrates saccadic eye movements associated with scanning the instrument panel and fixating at various instruments. In the last tracing the subject was instructed to blink his eyes five times. Note that these blinks (for this subject) appear only in the recording in the vertical axis and that one can readily discriminate between voluntary and involuntary eye blinks in these records.

Figure 2 depicts a 50-second segment of inflight recording from the same subject. The upper tracing is the output of the horizontal eye movement sensors. Left and right refer to deviations of the eye to the left or right. Examples of saccadic eye movements are also identified in this tracing. The second line depicts eye movements in the vertical plane as well as eyeblinks. Note that eyeblinks are generally associated with saccadic eye movements in either or both the horizontal or vertical plane. Line 3 is the graphic display of the time code. The same information for the next 25 seconds of data is displayed in the second set of tracings.

A number of analytical procedures have been em-

ployed to evaluate these data. The present report is based on a manual analysis of restricted portions of the flight. The portion of flight analyzed in each instance was a 6-minute 25-second segment of the recording (13-25 second periods). One segment was taken after being airborne for approximately 5 minutes, one 5 minutes prior to approach for landing and one segment midway between these two recordings. The analysis consisted of: (1) tallying the number of saccadic eye movements in the horizontal plane that occurred in each 25-second period. Saccadic eye movement producing more than 1 mm of pen deflection were counted; (2) saccadic eye movements in the vertical plane greater than 1/2 mm of pen deflection were counted; (3) number of eye blinks per 25 sec. period; (4) duration of longest period of no eye movement in horizontal plane per 25-sec. period.

The first three of these measures are self-explanatory; the fourth deserves some comment. For each 25 second segment we identified the longest time period that a subject remained fixated on one area. Our presumption was that with long periods of fixation the subject was either intensely looking at a given visual sector or that he was staring at something and not really seeing anything. Since the three periods of flight entering into the present analysis necessitated similar amounts of visual searching, we felt that if such time periods increased in duration as a function of time on task that we were probably not dealing with the pilot looking intensely at something but rather that we were dealing with periods of non-visual activity.

The choice of 25 sec. periods for the analysis was

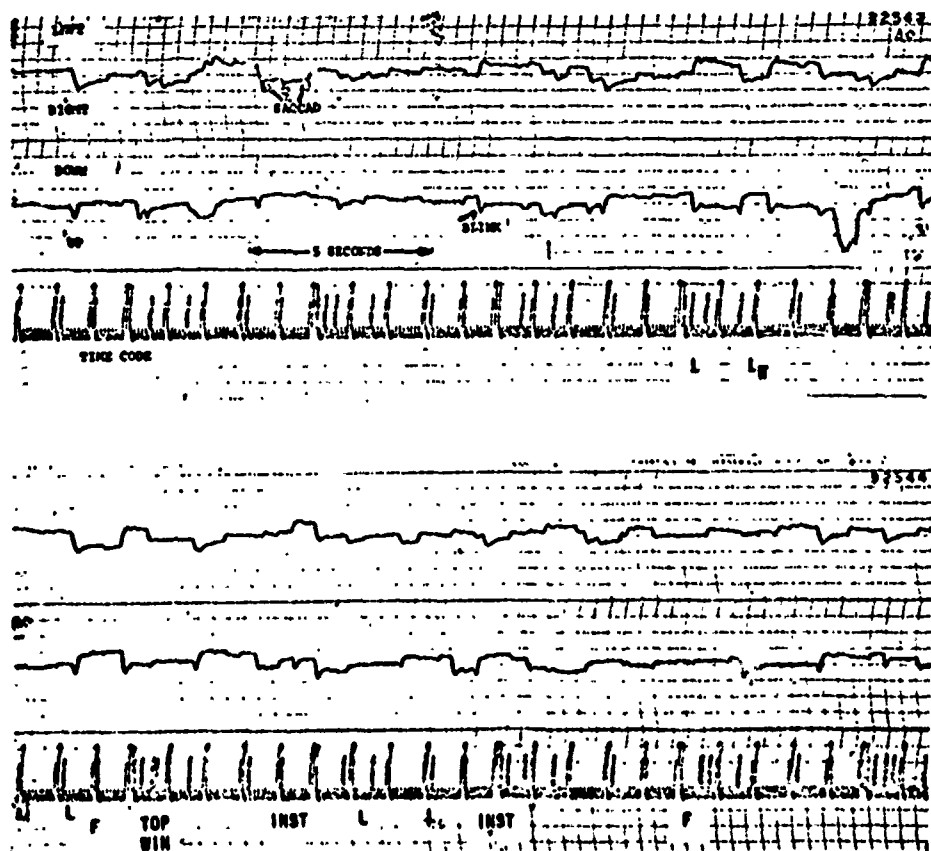


Fig. 2. Strip chart output of inflight eye movement recording. Upper tracing—eye movements in horizontal plane. Left and right refers to direction of pen deflection associated with eye movements to the left and to the right.

Second line—eye movements in vertical plane.

Third line—time code.

Fourth line—observer voice annotations: L—look to left; LW—look out of left window; F—front; Int—look at instrument panel; Top Win—Look toward upper portion of window.

based on the fact that at the paper speed we were recording (12 mm/sec) one page of our fan-fold paper depicted 25 seconds of data. Thirteen successive periods were chosen to allow for the development of an estimate of number of samples necessary to arrive at a reasonably stable and representative measure.

For each subject we thus analyzed four parameters of visual search. For each parameter three different time periods were analyzed and each time period consisted of 13 measures. For horizontal saccads, for example, we analyzed 13 (number of subjects per group)  $\times$  2 (skilled and unskilled group)  $\times$  3 (periods of analysis—early, mid and late in flight)  $\times$  13 (consecutive 25 second periods) samples, or a total of 1014 samples. These data were coded onto IBM cards and subjected to an analysis of variance design which allowed us to extract the effect of training (skilled vs. novice), period (Early, Mid, Late in flight) and trials (13 per subject for each period) and the interactions between these variables. Tables I, II, III and IV present the results of these analyses. Figures 3 and 4 depict plots of mean values for the 4 measures.

#### (1) Visual Search Activity in Horizontal Plane

As indicated in Table I, the effect of training was significant beyond the .01 level of confidence. The effect of "time on task" was also significant at the .01 level as was an interaction effect between training and time-on-task. Figure 3 depicts these results graphically and demonstrates the "cause" of the interaction effect. Skilled pilots produce significantly more saccads in the horizontal plane across the three periods when compared to unskilled pilots. They furthermore demonstrate a consistent decline in such activity over the three periods of analysis while the pattern over time is somewhat more complex for the unskilled group. The latter demonstrates a decline over the first two periods of analysis with an increase in the third period. Comparing the skilled and unskilled groups at the three points in time by the use of the "t" test, we find that the two groups are differentiated at the .01 level for the early and mid portion of the flight while the results for the late portion are not significant.

#### (2) Visual Search Activity in Vertical Plane

As demonstrated in Table II the training effect is not

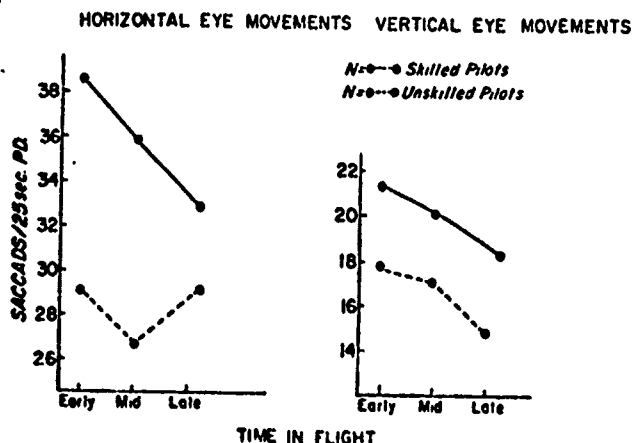


Fig. 3. Horizontal and vertical eye movement plots for early, mid, and late in the flight.

TABLE I. ANALYSIS OF VARIANCE OF HORIZONTAL EYE MOVEMENTS

Main Effect	df	F	P
A	1	8.27	<.01
S(A)-error a	24		
B	2	19.58	<.01
C	12	<1	NS
AXB	2	20.11	<.01
AXC	12	<1	NS
BXC	24	1.01	NS
AXBXC	24	1.29	NS
S(A)XBC-error b	912		
Total (26X3X13X1)	1013		

A—Training (skilled-novice).

B—Time of flight (early-mid-late).

C—Trials (13 - 25 sec. trials/subj./period).

S—Subjects.

TABLE II. ANALYSIS OF VARIANCE OF VERTICAL EYE MOVEMENTS

Main Effect	df	F	P
A	1	3.44	<.10
S(A)-error a	24		
B	2	37.51	<.01
C	12	<1	
AXB	2	<1	
AXC	12	<1	
BXC	24	<1	
AXBXC	24	<1	
S(A)XBC-error b	912		
Total	1013		

TABLE III. ANALYSIS OF VARIANCE OF INCIDENCE OF EYE BLINKS

Main Effect	df	F	P
A	1	1.88	NS
S(A)-error a	24		
B	2	5.91	<.01
C	12	<1	
AXB	2	14.81	<.01
AXC	12	1.18	NS
BXC	24	<1	
AXBXC	24	<1	
S(A)XBC-error b	912		
Total	1013		

TABLE IV. ANALYSIS OF VARIANCE OF "TIME-OUT" EFFECT

Main Effect	df	F	P
A	1	<1	NS
S(A)-error a	24		
B	2	4.80	<.01
C	12	<1	
AXB	2	1.17	NS
AXC	12	<1	
BXC	24	<1	
AXBXC	24	1.24	NS
S(A)XBC-error b	912		
Total	1013		

## VISUAL SEARCH ACTIVITY IN HELICOPTER PILOTS—STERN & BYNUM

significant, though it approaches significance ( $p < .10$ ). The effect of time on task is significant at the .01 level with none of the interactions significant. Figure 3 graphically depicts these results. Though the training effect is not statistically reliable the results are again in the direction of skilled pilots making more saccadic eye movements in this plane also. The effect of time on task again demonstrates a significant decrease of searching activity in this plane as well.

### (3) Eye Blinks

In the analysis of variance we find no significant training effect. Time-on-task is significant (.01) as is the interaction between training and time on task. As is apparent from Figure 4, the time on task effect is principally attributable to the decrease in blink rate seen in the novice pilot group, while the interaction effect is a function of the opposite effects of time on task on the two groups with the skilled pilot group demonstrating a slight increase in blink rate over time. Comparing the two groups at the three different points in time sampled in this study, it is only in the late time in flight comparison that a significant "t" ( $p < .04$ ) is obtained.

(4) For the last measure, the average "time-out" effect or average duration of non-searching in the horizontal plane the only effect which is significant is the time on task effect. There is a significant increase in the average time during successive 25 second periods that the pilot's gaze does not shift.

## DISCUSSION

The results clearly demonstrate that for all four measures there is a significant change in "visual activity" as a function of time on task. In all cases the result can be interpreted as suggesting a decrement in visual search activity over time. We see a decay in visual search activity in both the horizontal and vertical plane, indicating that there are fewer eye movements per unit time. There is an increase in the maximum duration of "no-search" activity over time, indicating that the duration of fixating a specific point becomes longer. The change in number of eye blinks over time measure suggests a differential effect between the two

groups over time. Though the training effect by itself is not significant the finding that there is a significant interaction effect between training and time on task makes for a slightly more complex interpretation of results. The time on task effect obtained is predominantly a function of the decrease in blinking over time seen in the novice pilot group. Our interpretation of the decrease in blinking seen in this group suggests that it is coupled with an attempt to compensate for "fatigue" effects by increasing attention. (We would like to rule out the possibility that the decrease is due to the taking of "cat naps" during time-out periods). At least one study has demonstrated that where task demands become greater blink rate decreases. Drew, Colquhoun and Long<sup>2</sup> evaluated blink rate in subjects driving automobiles under open road as compared to in-town traffic conditions and found markedly fewer blinks during the latter as compared to the former driving condition. What we would like to suggest here is that task demands are one factor determining blink rate and that task demands may be affected by both the demands of the objective situation as well as the state of the organism.

Our impression is that not only is there a decrease in the number of saccadic eye movements but that the angular displacement of the eyes also decreases. Thus we suggest that there is not only a decrease in the absolute number of eye movements or discrete fixations but that the area searched also becomes constricted.

The extent to which horizontal and vertical plane eye movements are independent of each other may be questioned. These two sets of data are presently being subjected to a correlational analysis to determine the extent of covariation. Our impression is that for many subjects they covary. There are, however, subjects in whom such covariation is not observed. For example, a number of our novice pilots spend considerably more time "searching" in the vertical as compared to the horizontal plane. Our interpretation of this is that they are spending more than the normal amount of time in looking at their instruments and that this detracts from visual searching in the horizontal plane.

The other subjective impression we have from our data is that pilots, novice perhaps somewhat more than skilled pilots, do not divide their visual search activity in the horizontal plane to the entire panorama displayed in front of them but that they pay more attention to the right sector of their visual field than the left sector. Since the pilot flies the craft from the right side and has a copilot or instructor pilot sitting to the left of him, this suggests that he is dependent on the copilot to keep him informed about what is going on in the left sector of his visual field and that novice pilots may be more dependent on their copilots for this type of informational feedback than is true of our skilled pilots. These subjective impressions, can, with some difficulty be empirically investigated with our data.

One further observation which has fascinated us is the efficiency with which man's brain programs visual activity. It has been demonstrated that while the eye is in motion (during a saccad) visual acuity is markedly attenuated. It is also quite obvious that while one is

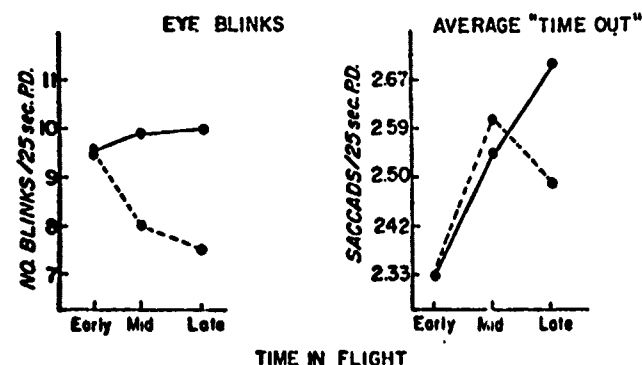


Fig. 4. Incidence of eye blinks for early, mid, and late portions of the flight. (Left portion). Incidence of non-search activity during early, mid and late portions of the flight (Right portion).

blinking one's ability to see is markedly reduced. Thus, for greatest efficiency, one would program a system to perform these two functions concurrently. This is exactly what our brain does. Note in Figure 1, that every eye blink occurs in association with a saccadic eye movement. For example, the labeled blink is associated with an eye movement to the left and up while the next blink is tightly coupled to an eye movement to the right and down. We again have the impression that this tight coupling of two bits of behavior which produce impairment in vision, breaks down as a function of time on task. In other words in late segments of the recording we more often observe eyeblinks that are not coupled with eye movements in either or both the horizontal and vertical planes. These observations will again be checked out on the data in our hands.

We would like to conclude with some comments about the utility of the recording of visual search activity for both the problem of flight training and safety.

We have demonstrated that it is technically feasible to reliably obtain artifact free recordings of visual search activity in an operational situation. Such recordings can be obtained without discomfort to the subject, and without markedly interfering with either training or flight conditions. Our results indicate significant differences in a number of parameters of visual search activity during the relatively simple task of flying a helicopter in a cross-country flight. We suspect that such differences will be magnified under more strenuous flight conditions. We suspect that it is feasible to develop a data acquisition and reduction system which will give the pilot instructor immediate feed-back about the adequacy or extent of visual search activity his student pilot is engaged in. This measure might also be used, at least as an adjunct to the pilot instructor's evaluation of the adequacy of performance of his student.

The fact that both skilled and unskilled pilots demonstrated decrements in visual search activity as a function of time on task suggests that such a data acquisition and reduction system might also be useful to inform pilots when their performance (i.e., visual search activity) is decaying and allow them to take the necessary corrective action.

A third, and potentially most important application of these findings, suggests that visual search activity might be used as a criterion measure for the evaluation of efficiency of performance and decrements in per-

formance as a function of time on task often referred to as "fatigue" effects. Other measures, which do not entail the instrumenting of the pilot, but are concerned with the instrumentation of pilot "outputs"—such as the various controls he has to manipulate, can be correlated with the criterion measure and their potential utility as safety and/or feed-back devices explored.

## SUMMARY

Visual search activity was recorded in 13 skilled and 13 unskilled pilots while flying the UH-1D helicopter during a cross country flight of approximately 50 minutes duration. The results demonstrate that skilled pilots engage in significantly more visual search activity in the horizontal plane than is true of novice pilots. Both skilled and unskilled pilots demonstrate changes in visual search activity as a function of time on task. These changes are:

- (1) A decrease of searching in the horizontal plane
- (2) A decrease of searching in the vertical plane
- (3) An increase in the amount of time not engaged in search activity per unit time.
- (4) A decrease in eye blinks.

These results are interpreted as suggesting a decrease in visual search activity over time. Applications of this procedure to problems of flight training and flight safety are briefly discussed.

## ACKNOWLEDGMENT

We would like to thank a number of people without whose assistance and active collaboration this research would not have been possible. Major Fred Dunaway of the Evaluation Division of the Office of the Director of Instruction, for his unfailing effort in recruiting subjects and in acting as pilot observer in many of these runs; to Mr. John Burton for setting up the recording instruments; to Mr. Shang-Chun Chen for his help in analyzing the data and last but not least, the pilots who so generously gave of their time to make this research possible.

## REFERENCES

1. BYNUM, J. A., and J. A. STERN: Painted helicopter rotor blades and flicker vertigo. *Aerospace Med.* 40:622-631, 1969.
2. DREW, G. C., W. P. COLQUHOUN and H. A. LONG: Effect of small doses of alcohol on a skill resembling driving. *Brit. Med. Jour.* 2:993-999, 1958.

# Computer Analysis of Eye Movement Patterns During Visual Search

MARK TROY, S. C. CHEN and JOHN A. STERN  
Washington University, St. Louis, Missouri 63104

TROY, M., S. C. CHEN and JOHN A. STERN. *Computer analysis of eye movement patterns during visual search*. Aerospace Med. 43 (4): 390-394, 1972.

Eye movements were recorded from 13 novice and 13 skilled helicopter pilots during a cross-country flight. This analysis is restricted to an evaluation of the pattern of eye movements as a function of (a) skill and (b) time on task. No differences were found as a function of skill. The incidence of non-patterned search activity was found to decrease as a function of time on task. The results are discussed in terms of a decrease in alertness to "unexpected" environmental stimuli. The development of a reliable computer-based procedure (utilized in the present study) for analyzing eye movements is also discussed.

**T**HIS REPORT IS A CONTINUATION of our studies on visual search activity in helicopter pilots. In an earlier report (Stern and Bynum<sup>13</sup>) we demonstrated significant changes in the incidence of saccadic eye movements (in the horizontal plane) over various portions of the flight (a one-hour, cross-country flight) as well as significant differences in such activity between skilled and novice helicopter pilots. The above results were based on a manual (perhaps better called visual) analysis of the data. The current report focuses on the development of a reliable computer based analysis of the same data and an extension of the previous analysis.

It was our expectation that significant changes in the patterning of visual search activity would occur as a function of time on task as well as expecting significant differences in patterns of eye movements as a function of skill level. Brandt<sup>1</sup> and Vurpillot<sup>14</sup> have reported that patterning of eye movement represents systematic searching and was related to success at solving visual problems. Since piloting a helicopter can be considered a problem heavily loaded with visual activity, we hypothesized that (a) skilled pilots should demonstrate a higher incidence of patterned search activity than novice pilots and (b) there should be a decrement in patterned search activity in both groups as a function of time on task.

"This research was supported by Department of the Army Contract No. DA 49 193 MD 2715."

## PROCEDURE

**Subjects**—Two groups of Ss were utilized with 13 Ss per group. The skilled pilot group was composed of pilots who had considerable experience in piloting the UH1-D helicopter. The novice group consisted of student pilots at Fort Rucker who had been through basic flight training and were in the early stages of transition training on the UH1-D.<sup>13</sup>

**Instrumentation**—Ss were instrumented with Beckman bio-potential electrodes. One electrode each was placed at the outer canthus of the left and right eye, one electrode was placed immediately below the right eye and one immediately above the right eyebrow. Eye movements in the horizontal plane were obtained by recording the potential difference between the two electrodes at the outer canthus of the eyes. Vertical eye movement and eye blinks were recorded across the remaining two electrodes. The instrumentation is discussed in more detail in our earlier report.<sup>13</sup>

**Sampling Period**—The sampling periods utilized for analysis consisted of 100 continuous seconds of data taken on each of the five units of flight. Only saccads occurring in the horizontal plane were used in the present analysis.

**Pattern Identification**—We defined a pattern of eye movements as the occurrence of multiple saccads in the same direction. Thus, two saccads to the left would be a pattern of two. Conversely, we were able to identify single eye movements as those which were preceded by and followed by saccads in the opposite direction. Sample tracings of horizontal eye movement data are illustrated in Figure 1 indicating different types of patterns.

**Computer Analysis**—The data were stored on magnetic tapes in analog form and analyzed by a classic LINC computer. The data were sampled at a rate of 40 samples per second and digitized into the computer. An analog to digital converter changed each voltage range of  $\pm 1$  volt into  $\pm 127$  integers, each integer step being 8 millivolts. With this data in digital form we were able to obtain the derivative between successive samples using the first difference method. So, for any point in time we have both a raw signal and the difference between the raw signal and the preceding data point. This can be expressed as a real time data pair ( $X_i, \hat{X}_i$ ), such



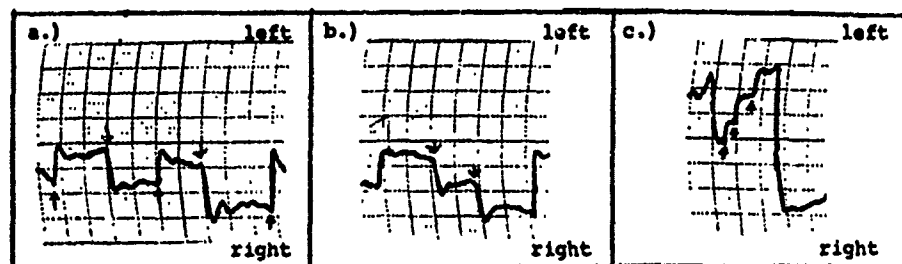


Fig. 1. Examples of eye movements recorded on strip chart paper. Arrows indicate saccads and the direction of each: (a) single unit saccads, (b) a pattern of two saccads to the right, (c) a pattern of three saccads to the left.

that  $\hat{X}_i = X_i - X_{(i-1)}$  where  $X_i$  is the raw signal,  $\hat{X}_i$  is the derivative signal, and  $i$  is the real time integer.

The next problem was to identify saccadic eye movements and to differentiate them from noise or other signals. This was accomplished by a simple algorithm, the basic logic of which is illustrated in Figure 2. The assumption underlying our algorithm is that voltage fluctuations which are large enough to initiate a change in state but which are unrelated to eye movements, will be transitory in nature, and will change state rapidly. Voltage changes resulting from eye movements, on the other hand, should maintain their state over several consecutive samples. Thus, by repetition of several steps in the algorithm, we are able to discriminate between saccads, other types of eye movements and noise.

The printout indicates, among other things, the direction and order of occurrence of each saccad. With this information, we were able to tally the saccads according to direction and to partition them into groups of 1, 2, 3, 4, 5, 6, 7 and 8 saccads. An example of a computer printout is presented in Figure 3.

**Statistical Treatment**—The results of the computer analysis of saccadic eye movements produced results were very similar to those of our manual analysis.<sup>13</sup> These results will thus not be presented below. What we are presenting here is an extension of our previous analysis, one which would have been practically impossible without the aid of the computer. The present analysis is restricted to an evaluation of the pattern of eye movements as a function of (a) skill and (b) time on task.

Since there were significant differences in incidence of saccadic eye movements between groups (skilled pilots made significantly more saccadic eye movements in the horizontal plane) and as a function of time on task (there was a significant decrement in the number of saccadic eye movements over time), and since in this analysis, we were concerned with comparisons of intra-subject changes as a function of time on task, we resorted to the following stratagem. We "normalized" the data for each individual by dividing single unit activity and the various groups of patterned activity by the total number of saccads produced during that portion of the flight and expressed these values as percentage of total activity. We then generated tables of percent unit saccad activities for the five portions of the flight: initial hover, early flight, mid-flight, late flight, and final hover for each S. (Since the hover maneuver utilizes a more restricted pattern of visual skills than is true of flying, we separated the three units of flight from the two units of hover and conducted independent analyses.) We next converted the percent saccads for the three periods of flight into ranks, the lowest rank assigned to the high-

est percentage. An analysis (of these ranks) was conducted on the array of ranks within groups. We generated a matrix in which rows represented the ranks for

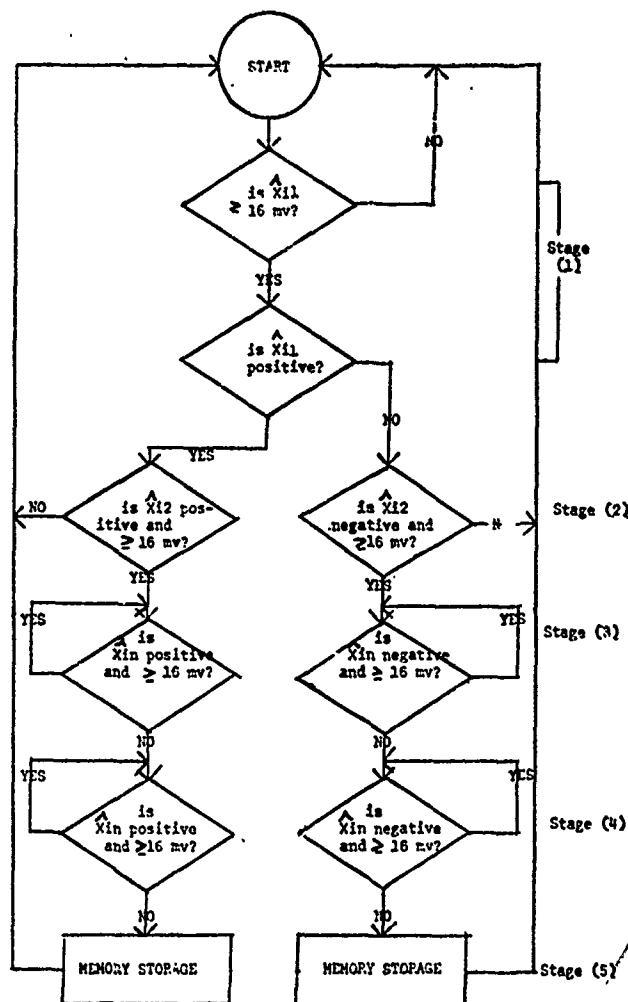


Fig. 2. Sampling of  $\hat{X}_i$  Values. The sampling is initiated at START and goes to stage (1) to await  $\hat{X}_i$ . If  $\hat{X}_i$  is above a defined level (dependent upon background noise), the program goes to stage (2). At stage (2), a second sample ( $\hat{X}_{i2}$ ) is taken. If  $\hat{X}_{i2}$  is below the defined level, the program returns to START. If acceptable, the program moves to stage (3). Stage (2) is, thus, a test for noise. Stage (3) is a dummy state. Since it has now been determined that an eye movement is occurring, the program remains at (3) awaiting the offset. If the signal maintains direction, it loops back to (3) if it changes direction above a stated value, it goes on to (4). Stage (4) is another test for noise. If the change in direction is maintained on the next sample, the program goes to (5). If it is not maintained, it remains at (4), until the next change. Stage (5) stores amplitude, time and directional information and returns to the start.

each S and columns represented the units of flight. Each cell, therefore, indicated the frequency of a particular rank on a particular unit of flight. A chi-square test was then performed on the data.

This procedure was derived from the methods of the Friedman Analysis of Variance and the chi-square test.<sup>12</sup>

## RESULTS

The results showed a decrease in the percentage of single eye movements over the three portions of flight. Although the absolute percentage changes are small, they are consistent; e.g., of the 13 pilots in the skilled group, four pilots displayed the characteristic pattern of decrease (rank order 1-2-3) and six other pilots indicated variations of this pattern (1-3-2 or 2-1-3). These three patterns (1 in the first position and/or 3 in the third position), out of the six possible, account for the search pattern of 77% of the skilled pilot group. The chi-square analysis indicated that this decrease was significant at the .01 level for skilled pilots, approached significance for novice pilots and was significant at the .001

level for the pooled data. A chi-square analysis of the initial and final hovers showed a decrease that was significant at the .01 level for the skilled pilots, approached significance for novice pilots, and for the pooled data, was significant at .05. Table I depicts the average percentage of patterns of search for our subject group.

The percentage of single eye movements was then pooled with the percentage of patterns of two. Although this represented about 80% of total eye movements, a chi-square analysis again indicated a decrease over the three portions of flight. This decrease was significant at .05 for skilled, .05 for novice, and .01 for the pooled data. The decrease was not significant for initial and final hovers.

No between group differences were found and across time differences were in the same direction for both groups.

Since the present analysis is based on the same raw data utilized in the Stern and Bynum report,<sup>13</sup> with the exception that the data in the present report were abstracted from the raw data by the use of a computer rather than the "eyeball", we correlated the total counts (number of saccadic eye movements) obtained by the two analyses. The correlations are based on data of 11 Ss selected at random from the novice pilot group. The correlations for the five segments of flight (initial hover, .991; early flight, .826; mid, .920; late, .931; and final hover, .985) indicated that we had, with reasonable fidelity, reproduced with the computer what we were doing in our eyeball analysis. We further recomputed the statistics presented in the above paper utilizing the data from our computer output with identical results.

## DISCUSSION

We had previously demonstrated decrease in *absolute* amount of visual search activity as a function of time on task as well as less searching for novice as compared to skilled pilots. The present analysis partialled out the effect of absolute differences in visual search activity as a function of time on task or training, and evaluated *alterations in search patterns* as a function of time on task.

TABLE I. MEAN PERCENTAGE OF PATTERNS OF SEARCH

	Skilled Pilots								1 + 2
	1	2	3	4	5	6	7	8	
Early	53	29	13	4	1	0	0	0	82
Mid	53	26	14	6	2	0	0	0	79
Late	50	28	14	4	2	1	0	0	78
Init. hover	50	29	14	5	1	0	0	0	79
Final hover	47	29	15	6	2	2	1	0	76

	Novice Pilots								1 + 2
	1	2	3	4	5	6	7	8	
Early	57	27	13	3	1	0	0	0	84
Mid	50	31	14	4	1	1	0	0	81
Late	53	24	14	6	3	0	0	0	77
Init. hover	47	31	16	5	1	0	0	0	78
Final hover	49	30	15	5	0	1	0	0	79

	Pooled Data								1 + 2
	1	2	3	4	5	6	7	8	
Early	55	28	13	4	1	0	0	0	83
Mid	51	28	14	5	2	1	0	0	79
Late	51	26	14	5	2	1	0	0	77
Init. hover	48	30	15	5	1	0	0	0	78
Final hover	48	29	15	6	1	1	0	0	77

Fig. 3. Example of a printout from the classic LINC computer listing each saccad in order of occurrence. Each time integer represents 100 milliseconds. Each amplitude integer represents 8 millivolts. Real Time is time which has accumulated since the start of the data analysis. Elapsed Time is time from the preceding saccad. Example of single saccads and groups of two and three are identified. (Labels are supplied by the authors.)



We had hypothesized that the decrease in visual search activity previously reported was a function of changes in the pattern of search activity. Our assumption was that the incidence of "many saccad patterns" would be most affected by the experimental manipulation. Our results demonstrate the opposite to be the case, namely, a restriction in relative frequency of unit saccads. There is considerable discussion in the literature concerning the question of decrements in visual search as a function of time on task, as well as discussion concerning the nature of this decrement.<sup>2,5,9</sup>

Various authors have observed that some portions of the visual field will be fixated with greater frequency than other portions. Mackworth and Morandi<sup>7</sup> reported that when Ss viewed photographs a few outstanding areas within the pictures received high concentrations of gaze. These areas were judged to be very recognizable and contained unpredictable contours or unusual details. Areas with simple, predictable contours were equally recognizable but seldom fixated. Their results supported the view that perceptual learning improved the ability to discern distinctive features in a stimulus array. Schroeder and Holland<sup>11</sup> were able to establish control over the frequency of fixation upon a given quadrant of the visual field as a function of the schedule by which fixations were reinforced by signal presentation. This was also demonstrated by Rosenberger et al.<sup>10</sup> and supported Neisser's findings<sup>8</sup> that information already assimilated determines where new information will be sought. Enoch<sup>12</sup> found that the structure and dimensions of the stimulus field plus the postural interactions with the stimulus field determine the areal pattern of eye fixations. This was supported by Gould<sup>4</sup> who found more fixations concentrated at the upper and right portions of a matrix display than at all other portions. Brandt<sup>1</sup> found a similar effect in a study of advertising technique.

In the present study, therefore, the decrease in the percent of single movements and the increase in percent of movements occurring in patterns may represent increasing concentration of gaze upon certain important stimuli or certain restricted portions of the visual field. This would imply that searching of the entire visual field is being abandoned to some extent with the result that the likelihood increases that some important stimuli will be missed. The studies reviewed above all dealt with visual search activity of static displays. In our study, we are dealing with a somewhat more complex situation, namely, a dynamic display which has to be scanned while the pilot is engaged in a complex motor and motor-visual integration task.

Thus there are important differences between the stimulus field as presented to helicopter pilots and the stimulus field as presented to viewers of matrices and pictures as in the above studies: 1, stimuli can be expected to be distributed randomly throughout the visual field of the pilot as opposed to concentrations of stimuli in pictures, and, 2, boundaries can be expected to be diffuse or at least constantly changing in the helicopter pilot's field of view as opposed to the fixed boundaries of matrices. These differences limit our ability to generalize from static field situations to the dynamic visual

field as viewed from a helicopter.

The rationalization which we feel best accounts for our results is the following. Let us assume that visual search in a helicopter has to be defined as random searching of a relatively large visual field. The pilot spots something "unusual" (such as another moving object) with peripheral vision and shifts it into central vision. If the stimulus has "value" to the pilot, he will systematically scan it, probably utilizing a pattern of saccadic eye movements. Should the stimulus turn out to be of low information value to him, he will shift to other objects in the visual field. Thus, a high incidence of unit saccads is interpreted as being highly alert to a great variety of visual environmental inputs. A reduction of this type of activity is, we believe, indicative of a decrease in alertness to "unexpected" environmental stimuli.

Another possible explanation is that there may be a change in the efficiency of peripheral vision. Gould<sup>4</sup> found that under normal conditions the more easily seen aspects of the stimulus field are detected with the same amount of accuracy either in the fovea or periphery. Mackworth<sup>6</sup> found that when the whole stimulus pattern becomes more complex, extraneous visual stimuli destroy peripheral recognition. He suggests that with considerable overloading the visual image is formed from the center outwards; visual noise, therefore, produces temporary tunnel vision. Moreover, if scanning is inwards (towards the center), recognition would be impaired to an even greater extent. It may be, therefore, that visual noise in the pilot's visual field is producing tunnel vision requiring more saccads per stimulus to obtain recognition.

One further result deserving discussion is the fact that when we partialled out differences in absolute number of saccads and restricted our analysis to relative patterns, the differences between skilled and novice pilots previously reported disappears. Thus, the pattern of searching, or the change in the pattern of searching as a function of time on task, does not appear to change as a function of the development of skill in flying the UH1-D.

The limitations of our data require us to be cautious in explaining our results. More information concerning the nature of the stimulus field and the pilot's position with reference to it would strengthen our findings. Another look should be taken at our definition of patterns. We have considered only one possible component of a pattern, namely, direction. Another component could be the excursion or distance the eye travels between fixations on the assumption that systematic searching would involve excursions of uniform length. It may be that when systematically searching a dynamic field, the length of the saccads would be more important than the direction of the saccads.

The development of patterns of eye movements appears to be an important component of visual search activity, one which has received too little attention in the past. The development of these patterns as a function of time on task, as indicated by our results, has important implications for those engaged in prolonged visual search. Further research is needed.

## REFERENCES

1. BRANDT, H. F.: *The Psychology of Seeing*. New York, Philosophical Library, 1945.
2. CARMICHAEL, I., and W. F. DEARBORN: *Reading and Visual Fatigue*. Boston, Houghton Mifflin, 1947.
3. ENOCH, J. M.: Effect of the size of a complex display upon visual search. *Jour. Optical Soc. Am.* 49:280-286, 1959.
4. GOULD, J. D., and A. SCHAFER: Eye movement patterns in scanning numeric displays. *Perceptual and Motor Skills* 20:521-535, 1965.
5. HOFFMAN, A. C.: Eye movements during prolonged reading. *Jour. Exper. Psychol.* 30:95-118, 1946.
6. MACKWORTH, N. H.: Visual noise causes tunnel vision. *Psychonomic Science* 3:67-68, 1965.
7. MACKWORTH, N. H., and A. J. MORANDI: The gaze selects informative details within pictures. *Perception and Psychophysics* 2:547-552, 1967.
8. NEISSER, U., and A. STOPER: Redirecting the search process. *British Jour. Psychol.* 56:359-368, 1965.
9. POULTON, E. C.: On reading and visual fatigue. *Am. Jour. Psychol.* 71:609-611, 1958.
10. ROSENBERGER, P. B., M. FISCHMAN and I. GOLDBLUM: Eye movement as an operant under discriminative and reinforcing control. *Communications in Behavioral Biology A*, 4:139-149, 1969.
11. SCHROEDER, S. R., and J. C. HOLLAND: Operant control of eye movements during human vigilance. *Science* 161:292-293, 1968.
12. SIEGEL, S.: *Nonparametric Statistics for the Behavioral Sciences*. New York, McGraw-Hill, 1956.
13. STERN, J. A., and J. A. BYNUM: Analysis of visual search activity in skilled and novice helicopter pilots. *Aerospace Med.* 41:300-308, 1970.
14. VURPILLOT, E.: The development of scanning strategies and their relation to visual differentiation. *Jour. Exper. Child Psychol.* 6:632-650, 1968.